Grassland – the source of a sustainable future

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Summary

- During the four year period from 2019-2022, the difference in annual grass DM production between the top 25% and bottom 25% of farms recording data in PastureBase Ireland was 4.9 t DM/ha.
- By optimising soil nitrogen (N) mineralisation, incorporating clover into grass swards and refining chemical N fertiliser input, the total N supply available to a sward can range between 450-500 kg N/ha (soil N + legume N + chemical N).
- Precision N management (using grass growth predictions and grass measurement) is a key tool to optimise grass production and minimise N loss.
- Grass-clover swards with 20% clover content can produce between 12.5 to 14.5 t DM/ha with 150-200 kg chemical N/ha.
- Incorporating white clover into swards and reducing chemical N fertiliser application according to sward clover content can reduce farm gate N surplus.
- Over-sowing clover is an effective option to increase white clover content in grazing swards without reducing farm pasture DM production.

Introduction

The EU Green Deal Farm-to-Fork strategy has set a target to reduce nutrient losses by at least 50% and fertiliser use by at least 20% by 2030. Water quality is regulated in the EU and Ireland by the Water Framework Directive (WFD; EC, 2000), which requires at least "good" water quality in all EU water bodies (rivers, lakes, groundwater, and transitional coastal waters). In Ireland, this must be achieved by 2027. The ecological status of Irish surface waters and groundwater are better than most EU countries; 54% of Irish surface waters have either a good or high status compared with 44% in the EU, and 92% of groundwater has good status compared with 80% in the EU (EPA, 2022). The average annual national use of N during the four year period from 2018 to 2021 was 373,365 t/year, peaking at 408,495 t in 2018. In 2022, the nitrogen (N) use in Ireland reduced to 343,000 t, in part due to increased cost as well as supply issues. The current target for N use in the agriculture sector is to reduce N fertiliser application to 300,000 t by 2030.

On grazed grassland, excessive N application in the form of chemical N fertiliser, slurry and N fixation are drivers of N loss to waterways, particularly in the form of nitrate leaching. Climate factors such as rainfall and soil temperature impact N mobility within the soil, and have a major influence on nitrate leaching. There are many challenges facing Irish agriculture, including environmental emissions reduction targets, reduced N fertiliser allowances and rising production costs. Grassland continues to be the lowest cost feed for milk and meat production systems in Ireland and ensuring optimum production of adequate quantities of high quality pasture must continue to be an important management focus of dairy farmers. In addition, grassland contributes to carbon (C) sequestration and increased biodiversity. This paper will provide the latest research findings and current best practice in pasture-based dairying systems, specifically looking at herbage production, and use of grass-white clover swards to reduce the environmental footprint and improve productivity. In the current environment of reduced chemical N fertiliser allowances and use, it is crucial that grazing and conservation legumes (white and red clover) are seamlessly incorporated into pasture-based production systems.

Current herbage DM production on dairy farms

The number of grassland farmers using Pasturebase Ireland (PBI) has increased significantly in recent years. Using PBI to provide information on grass supply on farm, combined with current and predicted grass growth rates has facilitated more efficient use of grazed grass.

From 2019-2022, overall DM production on the milking platform has declined from 13.6 t DM/ha to 12.2 t DM/ha (Table 1). Much of this reduction is a result of a decline in the quantity of silage harvested from the grazing platform. While the average number of defoliation events (i.e. grazing or silage harvesting) over the four year period was static at 7.9, two additional grazing events occurred on the top 25% of PBI farms compared with the bottom 25%. In many cases, the extra grazing events occurred because the frequency of grazing was quicker on these farms, especially in the earlier half of the grazing season. Each grazing event equates to approximately 1,300-1,600 kg DM/ha. Over the last four years, the difference in pasture DM production between the top 25% and bottom 25% of farms in PBI was 4.9 t DM/ha, which equates to enough feed (grazed grass and grass silage) for approximately one full livestock unit. The impact of grazing management decisions on herbage production is often overlooked when examining the variation in production performance between farms.

Table 1. *Average herbage DM production and the range in performance of the top and bottom 25% of farmers completing >30 covers in PastureBase Ireland from 2019 to 2022*

	Total DM production (t DM/ha)	Grazing DM production (t DM/ha)	Silage DM production (t DM/ha)	No. of grazings	No. of silage cuts	No. of defoliation events (grazing and/or silage) per paddock
2022						
Average	12.2	10.8	1.3	7.7	0.4	8.1
Top 25%	14.4	12.8	1.6	8.6	0.4	9.0
Bottom 25%	9.9	8.9	0.95	6.8	0.3	7.1
2021						
Average	12.7	11.1	1.7	7.4	0.5	7.9
Top 25%	15.2	13.0	2.1	8.3	0.5	8.8
Bottom 25%	10.2	9.1	1.2	6.5	0.4	6.9
2020						
Average	12.9	10.8	2.1	7.0	0.6	7.6
Top 25%	15.6	13.1	2.5	8.0	0.7	8.7
Bottom 25%	10.1	8.6	1.5	6.0	0.5	6.5
2019						
Average	13.6	11.3	2.2	7.2	0.7	7.9
Top 25%	16.0	13.2	2.8	8.0	0.7	8.7
Bottom 25%	11.5	9.7	1.7	6.5	0.5	7.0

Grazing management

In grazing systems, there is a very strong relationship between overall farm financial performance and grass utilised per hectare (Hanrahan *et al.*, 2017). The two key drivers of grass utilisation are stocking rate and supplementary feed levels. If the overall stocking rate is greater than or less than the grass growth and utilisation capacity of the farm, farm profitability will be reduced. It is critical that farms are stocked appropriately based on an accurate assessment of average grass growth and grass utilisation. For grassland farmers that can grow ≥14 t DM/ha, the appropriate stocking rate is 2.5 cows/ha, feeding approximately 500-700 kg concentrate/cow.

The key factors that influence pasture productivity include soil fertility, using high Pasture Profit Index (PPI) perennial ryegrass varieties, achieving a high number of grazing's per paddock and achieving the grazing targets throughout the year. The key grazing targets across the year are:

- >900 kg DM/ha opening farm cover – early February
- 550-600 kg DM/ha average farm cover – early April
- 160-180 kg DM/LU - mid-season
- 1,100 kg DM/ha - mid September

Mid-Season Management

The primary objective during the main grazing season is to maintain high animal performance from an all-grass diet, while at the same time maintaining high pasture quality. In general, from late April onwards, grass supply exceeds demand, and pre-grazing herbage mass should be maintained at 1,300 to 1,600 kg DM/ha, with a grazing residual of 50 kg DM/ha (4 cm post-grazing height). Excellent pasture quality is required to maximize animal performance from pasture in summer. From mid-April to mid-August, farm cover should be maintained at between 160 to 180 kg DM/cow with a rotation length of 18-21 days. During this period, aim to achieve six grazing rotations and utilize 8,000 kg DM/ha. Paddocks with surplus grass should be removed as they are identified to maintain grass quality while keeping them within the grazing rotation. In periods of exceptionally high growth rates, however, paddocks identified as surplus can be held for an additional period of time to increase silage yield and to better match growth rates and demand. Maintaining high herbage quality offers the potential to achieve further increases in animal performance from pasture.

During mid-season when grass growth exceeds herd demand, the N fertiliser application strategy needs to be carefully considered. For example, reducing chemical N fertiliser application will reduce the number of rotations with surplus grass which needs to be harvested as bales. Developing a mid-season N fertiliser plan for your farm in PBI can improve the management of N fertiliser as well as managing grass quality and supply.

Autumn Management

Typically, the grazing rotation length is extended from mid-August (+ 2 days/week) to allow for the build-up of large quantities of herbage before the decline in grass growth, allowing for the extension of the grazing season into November. Peak farm cover should be achieved in mid-September (~1,100 kg DM/ha). Achieving this will reduce supplementation requirement for the remainder of the grazing season. Autumn closing date is the main management factor influencing the supply of grass in early spring. To ensure that adequate quantities of grass are available at the start of the first rotation (early February), an average farm cover, at closing (1st December), of between 650-750 kg DM/ha is required and is dependent on individual farm demand (stocking rate). Farmers must calculate their own spring grass demand based on planned start of the first rotation, stocking rate, calving pattern and previous five year average spring grass growth rates on their farm, and implement an autumn closing strategy to facilitate the required opening farm cover in spring. The final decisions regarding closing strategy also require some consideration of the expected grass growth rate over the winter period.

Nitrogen supply in grassland systems

There is now a major focus on N fertiliser use in grassland systems. The N supply in pasture-based production systems comes from three sources:

- The soil (through N mineralisation)
- White clover in grazing swards (through biological N fixation)
- Applications of N (chemical and slurry).

All three of these N sources in pasture-based systems work alongside each other, and can influence each other. Improved grazing management allows for better coupling of C and N cycles with herbage production, soil organic matter and soil microbial biomass that increases overall plant growth. The expectation is that soil can supply between 100 to 200 kg N/ha per year through mineralisation of the N stored in the soil organic matter. The quantity supplied is very much dependant on the soil organic matter content, weather/climate conditions, soil microbial activities and grazing management practices. Chemical fertilisers can have both positive and negative impacts on soil N mineralisation. Chemical fertilisers provide essential nutrients (mainly N, P, K and S) that enhance plant growth and pasture DM production. This increased plant growth can lead to increased C and N

inputs to the soil through increased root and shoot biomass, which can stimulate soil microbial activity and N mineralisation. Excessive use of chemical fertilisers can lead to an imbalance of nutrients in the soil and the leaching of nitrates, adversely affecting soil microbial communities and leading to soil acidification. This can result in a decrease in soil organic matter and a reduction in the capacity of the soil to retain nutrients. It is important to use chemical N fertiliser in moderation and in conjunction with other soil management practices.

Table 2. *Herbage DM production, herbage N yield from soil N mineralisation, herbage N yield from biological N fixation via clover and total herbage N yield (soil, chemical N fertiliser and biological N fixation) at Moorepark and Clonakilty*

Location	Sward type	Chemical N application rate (kg N/ha)	Paddock herbage DM yield (t DM/ha)	Herbage DM yield from zero N plots within each paddock (t DM/ha)	Herbage N yield from soil mineralisation (N from soil) (kg N/ha)	Herbage N yield from biological N fixation via clover (kg N/ha)	Total nitrogen yield (kg N/ha) (Sum of N yield from chemical N fertiliser, soil N mineralisation and biological N fixation)
Moorepark	Grass-only	225	14.7	7.8	182	0	407
	Grass-clover	150	12.5	9.1	185	101	436
Clonakilty	Grass-only	200	12.1	8.0	202	0	402
	Grass-clover	200	13.4	11.5	202	103	505

Source: *(Murray and Hennessy, unpublished)*

White clover has the capacity to fix atmospheric N and make it available for plant growth. This occurs through a symbiotic relationship whereby rhizobia bacteria in the soil infect clover root hairs and form root nodules. The clover then supplies the bacteria with energy (from photosynthesis) to fix N, which is available to the clover plant and other plants for growth. Biological N fixation is very dependent on the sward clover content. A number of Teagasc experiments reported that the quantity of N fixed in grass-white clover swards was generally around 100 kg N/ha once the clover content is >20% (see Table 2). If the clover content is too high, however, total DM production can be reduced due to inadequate levels of perennial ryegrass in the swards to utilise the additional N fixed by the clover and can result in an increase in N losses.

The pasture DM production and N yield from grass-only and grass-clover swards in Moorepark and Clonakilty is summarized in Table 2. The overall N supplied to the grass-only and grass-white clover sward was 407 kg N/ha and 436 kg N/ha, respectively, at Moorepark. At Clonakilty, the overall N supplied to the grass-only and grass-clover sward was 402 kg N/ha and 505 kg N/ha, respectively. Herbage N yield from soil N mineralisation accounted for 184 and 202 kg N/ha at Moorepark and Clonakilty, respectively. At Clonakilty, the sward white clover content was 16.5%, while it was 22% at Moorepark. White clover contributed a herbage N yield of 102 kg N/ha via biological N fixation at both sites. The results of the research clearly show that biological N fixation can contribute to the N supply in well managed clover swards. At both sites, when the quantity of N supply from all three

supply sources was combined (soil N mineralisation, chemical N fertiliser and biological N fixation), the N supply was greatest in the swards that included clover despite having a lower chemical N fertiliser input.

What is Precision Nitrogen Management and why is it required?

To-date, chemical N fertiliser application guidelines have very much followed a calendar pattern. In recent years, however, weather patterns in spring, summer and autumn have all been very unpredictable, with no two consecutive years following similar patterns for rainfall and daily temperatures. The pattern of monthly rainfall for the last five years for Moorepark is summarized in Table 3. While the pattern of rainfall is very inconsistent between years, the total end of year total is generally very similar, even when there have been very dry periods within years. What is striking though, is that in 19 of the last 63 months (30%) rainfall was <50 mm (Table 3), which can result in soil moisture deficits during the main grazing season (April to September). In 2018, there was four consecutive months with <50 mm of rainfall from May to August, which had a severe impact on pasture production (-3 t DM/ha). In 2022, three months (May, July and August) recorded <50 mm rainfall. If this pattern of inadequate rainfall during the main growing months of the year continues, management practises need to change. Specifically, N management during these periods, as well as in spring, needs to be refined to achieve a better response to fertiliser and reduce the risk of nitrate leaching in autumn. It is not practical to depend solely on traditional calendar dates to apply chemical fertiliser, and instead live grassland data from Pasturebase Ireland and Met Éireann should also be used to maximise grass production and response to chemical N fertiliser application.

Table 3. *Mean monthly and total rainfall from 2018 to 2023 at Teagasc Moorepark. Months where rainfall was <50 mm are highlighted in yellow*

	2023	2022	2021	2020	2019	2018
January	104	43	60	10	66	138
February	17	97	190	153	57	40
March	144	83	53	48	118	89
April	53	69	23	65	109	175
May	51	44	131	37	26	49
June		73	27	73	88	32
July		34	63	73	35	43
August		28	58	145	107	43
September		140	102	43	72	60
October		230	125	102	155	72
November		165	33	119	141	167
December		90	135	153	115	168
Total	**369***	**1,096**	**1,000**	**1,021**	**1,089**	**1,076**

**Rainfall year to-date 2023*

Key points to follow on Precision Nitrogen Management

- *Match chemical N fertiliser application rate to grass demand, use the predicted growth rates in the Grass 10 newsletter*
- *Avoid spreading chemical N fertiliser when heavy rainfall and low soil temperature are forecasted (for example - in March 2023 there was no appropriate window to spread N)*
- *Cease N fertiliser applications mid-season when grass growth is less than 30 kg DM/ha*
- *Target lower N fertiliser applications when sward clover content is >20%*
- *Soiled water can be used strategically to replace chemical N fertiliser in grazing swards*
- *Test slurry samples to determine N content and adjust chemical N fertiliser application rates accordingly*
- *Replace some chemical N fertiliser application levels in spring in line with slurry applied using low emissions slurry systems.*

Long-term Clover research at Moorepark

Eight years (2013-2020; Table 4) of research at Moorepark have been completed comparing the standard grass-only grazing system receiving 250 kg fertiliser N/ha with a grass-white clover system receiving 150 kg N/ha. Average sward clover content across the season was 22%. The chemical N fertiliser application rate for each treatment was similar until late April (83 kg N/ha spread), after which the grass-white clover 150 kg N/ha treatment received 9 kg N/ha/month.

Although there was a 100 kg reduction in chemical N application, there was no difference in cumulative herbage production (13.6 t DM/ha). Approximately 75 kg DM/cow more silage was fed during lactation to the grass-white clover cows, mostly in autumn to extend the grazing rotation and to ensure peak average farm cover was achieved. Milk yield and milk solids yield were greater on the grass-white clover system compared with the grass-only system. Reduced chemical N fertiliser inputs and increased milk production contributed to increased net profit in the grass-white clover system compared with the grass-only system, with an overall increase in net profit from the grass-white clover system in the region of €404/ha based on 2022 input and milk prices.

Table 4. *Average animal and sward production on grass-only swards receiving 250 kg N/ha and grass-white clover swards receiving 150 kg N/ha from 2013 - 2020*

	Grass-only 250 kg N/ha	Grass-white clover 150 kg N/ha	Difference
Stocking rate (cows/ha)	2.74	2.74	-
Annual herbage production (t DM/ha)	13.8	13.5	-0.3
Silage conserved (t DM/cow)	1.00	0.98	-0.02
Silage fed during lactation (kg DM/cow)	259	333	+74
Average sward clover content (%)	-	22.0	-
Milk yield per cow (kg)	6,068	6,331	+243
Milk solids yield per cow (kg)	490	510	+20
Concentrate fed (kg/cow)	438	438	-
Nitrogen use efficiency (%) (2013-2016)	40	58	+18
Nitrogen surplus (kg N/ha)	141	63	-78

The farm gate N surplus for the grass-white clover system was low at 63 kg N/ha compared with 141 kg N/ha for the grass-only system. The National Farm Survey reported that the participating farms had an average farm gate N surplus of approximately 176 kg N/ha. Reducing farm gate N surplus is possible when average annual sward white clover content is approximately 20% or greater.

Incorporating white clover on commercial farms – Clover150 project

In 2021, a group of 36 farmers from across the country were enrolled in the five year Clover150 project. The farms included a range of land types, geographical spread, climate conditions and farming enterprises. White clover is being established on the farms through a combination of reseeding and over-sowing. The project objectives are to:

- Maintain herbage production ≥ 14 t DM/ha grown
- Reduce farm gate N surplus to <130 kg N/ha and increase farm gate N use efficiency (NUE) to >40%
- Reduce chemical N fertiliser application to ≤ 150 kg N/ha per year
- Maintain average sward clover content >20%

Increasing the clover area on farm

In 2020, the Clover150 farms had clover on <10% of their milking platform area; by April 2022, the average area with clover present had increased to 45%, and by the end of 2022, 64% of the milking platform area had clover. The project aims to have an average annual sward

clover content of >20% on 100% of the grazing platform. The increase in the clover area on the milking platform was achieved through a combination of reseeding and over-sowing, with approximately 15% of the milking platform over-sown annually. The main lesson learned from the first year of over-sowing (2020), was that it took place too late. Over-sowing must be completed early in the year (late March to early May) to have a successful impact. Data from the Clover150 farms shows that paddocks over-sown in the month of April had, on average, 20% sward clover content by the end of the sowing year, whereas paddocks over-sown from May onwards only achieved 14% sward clover content (Figure 1). Adequate soil moisture levels are essential at the time of over-sowing and in the first six weeks post-sowing. Over-sowing has proven to be a very successful method for rapid clover establishment on farms, and has been shown in the Clover150 farms to be as successful as reseeding in terms of establishing white clover. Across the farms, the over-sown paddocks had, on average, 15% sward clover content in the sowing year, while reseeded paddocks also had, on average, 15% sward clover content. The over-sown paddocks had greater herbage DM production in the establishment year compared with reseeded paddocks (13.2 vs 9.9 t DM/ha, respectively), mainly due to the over-sown paddocks remaining in the grazing rotation throughout the establishment period.

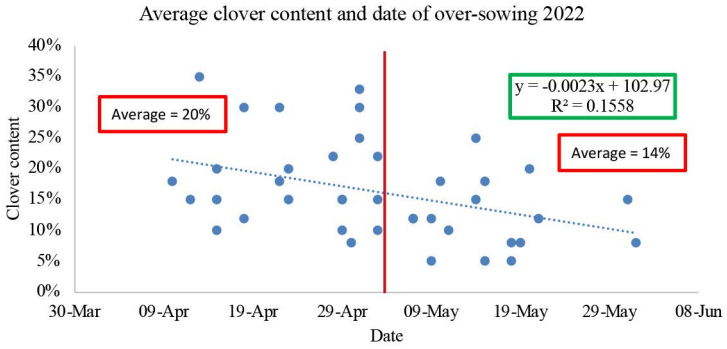

Figure 1. *The impact of over-sowing date on average sward clover content from three estimations in the sowing year on the Clover150 farms*

The impact of increasing the proportion of the milking platform containing clover on the Clover150 farms

PastureBase Ireland data for the last three years on the Clover150 farms shows that chemical N fertiliser application in 2020 was 232 kg N/ha and herbage production was 14.4 t DM/ha. In 2021 chemical N fertiliser application declined by 26 kg N/ha and pasture production was 14.1 t DM/ha. From 2021 to 2022 chemical N fertiliser application declined by a further 48 kg N/ha to 158 kg N/ha, and pasture production was 13.2 t DM/ha (Table 5), despite a considerable summer drought on the majority of farms in 2022. This reduction in chemical N application resulted in a significant improvement in farm gate N surplus and NUE on the Clover150 farms. Farm gate N surplus and NUE were 194 kg N/ha and 31%, respectively, in 2020. By the end of the third year (2022), the farm gate N surplus had reduced by 55 kg N/ha (to 139 kg N/ha), while farm gate NUE had increased to 39%. This improvement in farm gate N surplus and NUE was largely driven by the reduction in chemical N fertiliser application.

A worrying trend on the Clover150 farms is the increase in N/ha derived from purchased concentrate feeds, an increase of 11 kg N/ha from 2020 to 2022. It is vital that any reduction in chemical N fertiliser is not replaced by another form of purchased N, in this case N contained in concentrate or bought in feeds. When clover and N reductions are in place on farm, it is a vital that herbage production must be maintained on farms, highlighting the importance of targeted reductions in the use of chemical N fertiliser on clover paddocks within the farm.

Table 5. *Summary of Total N applied, chemical N applied and the annual dry matter produced*

	2020	2021	2022
Farm gate N surplus (kg N/ha)	194	179	139
Farm gate N use efficiency (%)	31%	33%	39%
Chemical N fertiliser application (kg N/ha)	232	206	158
Total N application (chemical and organic; kg N/ha)	254	240	197
Concentrate fed (kg N/ha)	41	43	52
Area under white clover (%)	10%	45%	64%
Herbage production (t DM/ha)	14.4	14.1	13.2

Altering nitrogen applications on grass-white clover swards

One of the major findings from the Clover150 farms has been the benefit of having a pre-planned paddock N fertiliser application plan in place. Regardless of the clover area on-farm, farmers should take the opportunity to plan the fertiliser N application for each paddock for the grass production year, which can result in reductions in chemical N fertiliser application, and better use of slurry N and soiled water N. The N Planner in PBI allows farmers to plan individual paddock requirements (grazing/silage and clover/non-clover) and tailor chemical and organic N fertiliser applications to individual paddocks. The level of clover in the sward, total N fertiliser applied and cumulative herbage production on paddocks on the Clover150 farms are summarised in Table 6. It is apparent that where sward clover content was >20%, a significant reduction in chemical N fertiliser application was achieved while maintaining high levels of herbage production. Reducing chemical N fertiliser application when sward clover content was <20%, resulted in a reduction in the quantity of herbage grown, highlighting the requirement for careful planning of the N fertiliser application strategy depending on the level of clover present in paddocks.

Table 6. *The impact of sward clover content and N fertiliser application on herbage production in paddocks on the Clover150 Farms*

Clover %	Area (ha)	Chemical N fertiliser application (kg N/ha)	Organic N application (slurry and soiled water) (kg N/ha)	Total N application (chemical and organic) (kg N/ha)	Annual pasture production (t DM/ha)
0%	430	180	24	204	12.6
<10%	455	161	21	183	12.4
10 - 20%	370	158	27	185	12.4
21 - 30%	266	130	29	160	12.9
> 30%	108	82	43	125	13.4

Conclusions

Careful planning of chemical N fertiliser application is necessary to increase pasture production and N responses, while also reducing the potential loss of N to the environment. New grazing management practises encompass improved seasonal grazing management, incorporation of legumes into grazing and silage swards and precision N management across the grazing season. White clover plays and will continue to play a key role in reducing the requirement for chemical N fertiliser, but also reducing farm gate N surplus while maintaining herbage production levels on-farm. Increasing sward clover content to >20% will allow herbage production to be maintained on farms, allowing chemical N fertiliser to be reduced. The major focus for dairy farms in the next two to three years will be to increase the clover content in swards (through reseeding and over-sowing), but also improving soil fertility and grazing management practises. Farmers should now begin accounting for the farm gate N surplus generated on their farms and identify avenues to reduce this surplus without compromising the overall pasture DM production of the farm.